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During the period covered by this report: (a) We carried out more than 15 fully parameterized experiments in addition to a number of smaller efforts; wealso made substantial progress in our theoretical work. (b) We published (including in press, submitted, and two that are in the last stages of preparation) 19 full length articles in peer-revived journals. (c) We made 37 presentations at professional meetings as either papers delivered at meetings or in symposia, or as posters. (d) One Master's thesis was also completed and a Ph.D. dissertation is in progress. (e) We have made substantial progress on 9 additional full-length articles that will be submitted to peer-reviewed journals.

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GRANT # F49620-94-1-0397 from the Air Force Office of Scientific Research
VISUAL PERCEPTION OF SPATIAL LOCATION AND ORIENTATION

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Final Report: July 1, 1994 - June 30, 1998
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Summary of Effort: During the period covered by this report: (a) We carried out more than 15 fully parameterized experiments in addition to a number of smaller efforts; we also made substantial progress in our theoretical work. The highlights from these are summarized in the section immediately below. (b) We published (including in press, submitted, and two that are in the last stages of preparation) 19 full length articles in peer-reviewed journals (listed below). (c) We made 37 presentations at professional meetings as either papers delivered at meetings or in symposia, or as posters (listed below). (d) One Master's thesis was also completed and a Ph.D. dissertation is in progress. (e) We have made substantial progress on 9 additional full-length articles that will be submitted to peer-reviewed journals.

Research Highlights:

1. We had subjects set the elevation of the hand to match the height of a target (five different heights) whose perceived elevation was visually mislocalized with the hand in the midfrontal plane (mislocalization generated by pitching a pitchroom or a pitched-from-vertical two-line stimulus in darkness. As might be expected the height match was to the perceived height of the target (e.g., with VPEL set 20^0 below true eye level the hand was set at true eye level to match a target that appeared at VPEL). For further work we installed a device (search coil) that permitted us to measure 3 dimensions of translation and rotation of the finger. Subsequent work was done with the finger at different distances from the body. Surprisingly, at full arm extension the subject's finger points accurately at a visually mislocalized target. Given these results we also made height matching measurements at intermediate distances and discovered that the accuracy of the process of manual localization is contingent on the distance of the finger from the body. The accuracy is thus monotonically related to distance with accuracy at full arm extension, settings that are displaced from accuracy for the VPEL error with the finger in the midfrontal plane, and a graded error for distances in between full extension and midfrontal plane.

2. We carried out three separate sets of experiments which showed that the influence of the pitch and/or roll of a line or lines on VPEL (visually perceived eye level) is independent from the mechanism controlling the perception of visual pitch: In one of these we showed that variation of VPEL is predicted by our combination rule over a large range of orientations for 2-line stimuli for which the perception of pitch orientation does not vary. In a second we found a nearzero correlation between the VPEL and perceived pitch measures across a group of 20 subjects. In a third experiment on a visual agnosic with carbon monoxide damage to the ventral stream in cerebral cortex, we found that although she could not manually match the pitch of a large pitchable surface, here VPEL-vs-pitch function was normal. Thus, we are able to conclude that the mechanisms mediating the influence of a visual field is dependent specifically on the orientation of individual lines in the field and is independent of the mechanism mediating the perception of pitch.

3. Of the two high-g sets of experiments we carried out (Brandeis, Wright-Patterson), one has been published; the second reported. In the first we found no influence of increase in g (to 1.5 g) on the slope of the VPEL-vs-pitch function, although a significant influence on the elevator illusion (y-intercept) ; in the second we found a significant influence of g (up to 4 g) on both the slope and the y-intercept of the VPEL-vs-pitch function. We have not yet completely resolved the basis for the differences in results in the two sets of experiments.

4. We found that the combination of two long lines yields an influence on VPEL that equals a little more than the average of the influences of the two lines separately viewed; with two short lines we obtain complete summation. Thus, for short lines as for long lines, the rule for combining influences from two spatially separate lines of the same or different orientations is linear, with only a difference in the magnitude of summation.

5. We found that the setting of elevation of a target mislocalized under the influence of a pitched-from-vertical single line is essentially independent of the elevation of the eye in the orbit, the elevation of the head on the neck, and the eccentricity of the direction of the eye in the orbit. Since, with the direction of gaze restricted to the midfrontal plane, we also find a significant influence of retinal eccentricity, this implicates the influence of extraretinal eye position information (EEPI) as a key contributor to the mechanism in control of the VPEL discrimination. This inference goes along with the fact that when a subject attempts to set the direction of gaze to eye level in the presence of a two-line pitched-from-vertical stimulus, the setting is accurately to the location to which the subject also sets a target so as to appear at VPEL. This latter set of measurements involves errors in perceived elevation of the direction of gaze by as much as 20^0 or more - a result of the biasing influences of the visual input on EEPI..

6. In a 1g environment we found substantial influences of the direction of the body (body-on-side, erect) on the slopes of the VPEL-vs-pitch and VPSA-vs-slant slopes and y-intercepts employing 2-line stimuli. These effects may be summarized by saying that the slopes of the induction functions were larger for the rolled-to-horizontal observer than for the erect observer, and for a given body orientation were larger for the VPEL discrimination than for the VPSA discrimination. Both the y-intercepts of the induction functions and the norm measured in complete darkness were lower when subjects viewed the vertical lines than when they viewed the horizontal lines; this held for both the VPEL and the VPSA discriminations. The effects of body orientation on the slopes and of line orientation on the y-intercepts result from the effect of gravity on the settings. These results are consistent with and may be graphed continuously with the influences we have previously measured with subjects in high-g.

7. We discovered that the very same individual lines that generate the significant influences on VPEL generate a sin4θ function of orientation for the VPV discrimination (visually perceived vertical with a 2-line around-the-clock stimulus).

8. Theoretical advances were made on several fronts: A computational neural model was developed and applied to the VPEL results from experiments which measured the influence of line orientation, line length, number of lines, and 2-line combinations of lines at all orientations. The model fits the results with all of these variations along large ranges of these parameters very well. The model makes use of a variable synaptic conductance that allows fitting to averaging for long lines and complete summation for short lines. Separately, we have fitted the results of varying orientation of 1-line and 2-line stimuli on both VPEL and VPV discriminations to a 3-dimensional space that has some resemblance to the classical treatment of color space: two of the dimensions are the circumference of the midfrontal plane (CMFP) and the central vertical meridian (CVM) of a projection sphere, and the third dimension is the line length. A cross-section through an inversion from this model shows the 2-dimensional basis along which the VPEL and VPV values have a simple representation.

9. In an experiment in which we measured the abilities of 18 subjects to find hidden figures in 3 different tests that are supposed to measure a global cognitive spatial ability - one of which has previously been found to be highly correlated with 'field-independence' - high correlations were found between the performance on the three test, but none of them correlated significantly at all with field dependence as measured by the elevation of VPEL.

10. We have recently been able to explain the surprising distance-contingent variation in accuracy of pointing, reaching, and height matching by a model that makes use of two processes: a distal process and a proximal process. The weighting of the two changes systematically with the distance of the finger from the body.

11. We have recently made measurements of the binocular depth contrast with a single long, pitched-from-vertical inducing line and a single short test line. The inducing line was horizontally displaced from the median plane and located at 25^0 eccentricity; the test line was located 8.3^0 from the median plane. With the inducing and test line on the same side of the median plane, the usual inducing function is measured with variation of the pitch of the inducing line. However, with inducing and test lines on opposite sides of the median plane, there is no induction. This result cannot be fit by either of the classical models or by any current model. We have been able to quantitatively model this surprising result with a two-channel model in which one of the two responds to the binocular disparity of retinal orientations and the second responds to the sum of the two retinal orientations of the lines.

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18. Hudson, T., Li, W. and Matin, L. (in preparation for submission to ***Nature***). One-sided binocular depth contrast and a two-process model for its explanation.
19. Li, W., and Matin, L. (in preparation for submission to ***Science***). Distance-contingent accuracy of pointing to a perceptually mislocated target.

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Hudson, T. (1997). Independence of perceptions of visual pitch (PVP) and visually perceived eye level (VPEL). Columbia University.